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ABSTRACT

Knowledge elicitation through programming was studied to determine students' intuitive ideas about motion. The subjects, 17-year-old sixth-form science students and 14-year-old third-form students, were asked to write expert systems programs about motion; and their interactions with their own knowledge were observed. The 17-year-old students had just completed a 2-year Physics course, and the 14-year-old students had received no formal instruction in Physics. The PROLOG programming language was chosen, since it provides a declarative programming environment and a built-in logical inference mechanism allowing the user to simply declare the relevant facts and inference rules; the resulting knowledge base can be put to work without extra programming effort. Results from the preliminary analyses indicate that it is possible to determine a students' conceptual framework regarding motion through PROLOG programming. It appears that the intuitive ideas are not compartmentalized with respect to learned physics concepts, but rather become woven into their own intuitive way of looking at the world of motion. The nature of integration depends largely on how well structured their own knowledge base about motion is. Three flowcharts are presented. (TJH)

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KNOWLEDGE STRUCTURES - WHERE CAN WE FIND THEM?

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INTRODUCTION

Over the past ten years, one of the major concerns amongst researchersin science education has been the problem of learners' pre-instructional ideas. It has been widely recognised that before students come to the science classroom, they already have developed some conception of the world around them and that such intuitive ideas very often persist despite instruction. Until very recently, most of the research has been focussed on where these ideas depart from the scientific view. Faced with the voluminous wealth of data from such research, mainly in the form of a catalog of misconceptions, many research workers in this field are recognizing the need to find a more comprehensive and deeper understanding of the nature of the students' alternative conceptions and different hypothesis are put forth for their interpretation. Some propose to look for a commonsense 'theory' of the content of alternative conceptions' which are 'more general than a set of rules about particular cases', capable of accounting uniformly for the various conceptions catalogued (Ogborn, 1985). Others, not expecting the students' conceptions to be consistent, structured theories, propose more pragmatic approaches, ranging from finding a set of correlational descriptions between situations and student responses (Viennot, 1985) to looking for a set of prototypes, not necessarily coherent, which the students would use to handle different situations (Guidoni, 1985).

There is no dispute that scientific knowledge is well structured, and so probablyis the expert's scientific knowledge. What about commonsense, intuitive ideas? Are they structured as well? How coherent or consistent

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are they, and how persistent? Furthermore, how does the learning of school physics interact with their intuitive ideas? Are the two domains of knowledge compartmentalized as some have alleged (Claxton G., 1985), or are they integrated? If it is the latter, what are the different modes of integration? These are important questions for the understanding of the nature of alternative concepts, and for providing insight into the process of learning in situations where the student comes to the classroom with a lot of pre-conceptions. The present research tries to look for answers to these questions by eliciting students' intuitive ideas about motion through asking them to write expert systems about motion, and to observe their interactions with their own knowledge so expressed.

METHODOLOGY

The methodology employed in this research is essentially one of knowledge elicitation through programming. The basic idea is that here the student plays the role of the teacher and the computer that of a learner. In the course of teaching the computer, the student is obliged to externalize his/her ideas. Once these ideas and intuition have been externalized, they become in some sense accessible to reflection. The advantage of having such ideas externalized in the form of an expert system is that it 'freezes' the students' ideas at a certain instant, allowing the student to use it to explore the logical consequences of the externalized knowledge and at the same time supporting easy modification when this isdeemed necessary.

An important prerequisite for such a scheme of work to be viable is the availability of a programming environment that is amenable to use and effective in representing commonsense knowledge. PROLOG is chosen for this research as it provides a declarative programming environment and a built-in logical inference mechanism so that the user only needs to declare the relevant facts and inference rules and the resulting knowledge base can then be put to work without extra programming effort. PROLOG also excels conventional languages in its ability to handle symbolic and non-numerical relationships and this is very important here since what needs to be elicited are qualitative intuitive ideas rather than mathematical relationships. In order to provide better programming support to the students, an expert system shell - APES (Hammond P. & Sergot M., 1984) - is provided to the students on top of PROLOG. This allows the computer to explain how it arrived at a certain result based on the rules it has learnt. Further, it allows factual information required for getting inference results to be entered through the 'query-the-user' factility during the course of running the expert system developed (Law N, Ogborn J. & Whitelock D., 1988).

An example dialogue between the student and the computer goes like this:

Student: object's motion caused by itself if object has force supplied to it by itself.

Student: bird's motion caused by what?

computer:bird has force supplied to it by what?

Student: itself

Computer:Answer is: bird's motion caused by itself.

Student: Why?

Computer:Bird's motion caused by itself because bird has force supplied to it by itself.

This study has been carried out with two groups of students. The first group was composed of sixth-form science students (17-yr- olds) who have just completed a two year O-Level course in Physics, while the second group was made up of form three students (14-yr-olds) who have had no formal instruction in Physics. Each student worked on the programming task for about seven sessions, each lasting approximately one and a half hours. The data collected include the developed programs, as well as screen dumps and diary notes taken during the programming sessions.

STUDENTS' PRIVATE PHYSICS

One objection that may be raised against using PROLOG as the means of elicitating children's ideas is that it places an artificial constraint on the students to express their ideas in the form of logical statements, whereas one would expect intuitive ideas to be much less structured and possibly much less logical. A careful look at the programs reveal that the students use the PROLOG programming environment as the medium to express what they think general rules about motion should be like, and the syntax of PROLOG does not seem to have posed too much restriction on expressing their intuitive ideas. A typical rule written by a student is as follows:

```
_object motion controlled by itself if
     _object force-supplied-during-motion _name-of-force and
     _name-of-force force-type internal
```

The students wrote their programs individually and they were discouraged from discussing their program with each other. From the wide difference in the overall content as well as structures of the programs written,

there was strong evidence that there had not been much of a collaboration between the students in this task.

At a first level of analysis, one may leave the data collected during the process of program development aside, and just concentrate on the resulting final programs written by the students. What do these programs tell us about students' conceptualization of motion?

If we look at the contents of the programs, we find that many of the rules display recurrent themes that reveal certain very pertinent patterns of reasoning which when taken together form a 'mental gestalt' of naive mechanics. Though the details of the rules written differ from one student to the next, the cognitive primitives used and the framework of reasoning are very similar amongst the students in both age groups. Fig. 1 below tries to depict the framework of reasoning in the form of a network:

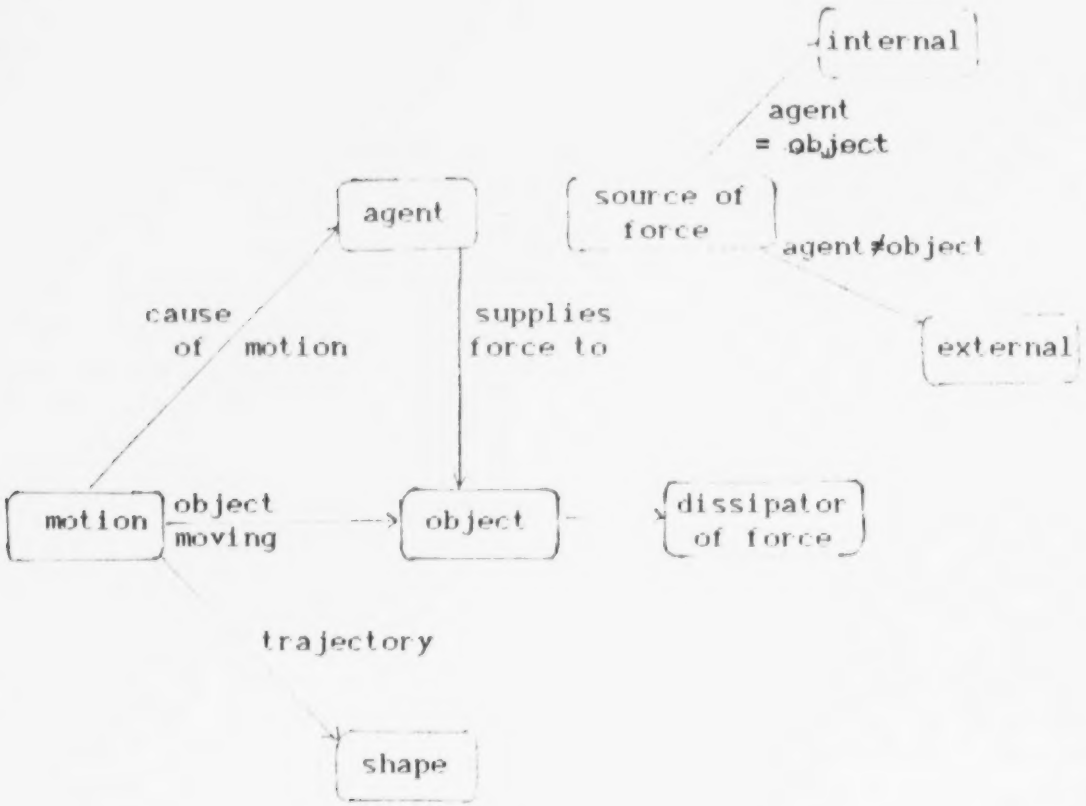

Fig. 1 Network showing the predominant framework of reasoning about motion

This framework (gestalt) of reasoning goes as follows: For any motion there needs to be a cause. The cause of motion is normally an agent, and the agent supplies the force needed for the motion. Thus force is seen as an entity that can be possessed by an object and can be passed from one object to another. Furthermore, the force would be dissipated by the moving object during the course of motion. In some instances the agent of causation can be the moving object itself,e.g. a bird flying in the air, and in such cases, the source of force would be termed internal, otherwise the source of force would be labelled external.

KNOWLEDGE STRUCTURES & INTUITIVE IDEAS

It would be an over-exaggerated claim to say that the structures of the students' programs are direct representations of the structures of the students' intuitive ideas, they nevertheless provide us with important information as to how they relate their various ideas and conceptions of motion together. There are four possible dimensions of looking at the degree of structuredness of the knowledge expressed in the programs:

i) whether there exists any prominent 'mental gestalt' as expressed in the program and their relative importance within the program,
ii) whether entities occupying the same syntactic role in similar relations share the same ontological status
iii) consistency in the nature of the conditions used for deciding among the same group of goal statements
iv) the inter-relatedness of the rules.

Note here that the point of interest is the structure of the expressed knowledge content per se and not the structure of the rules from the point of view of the PROLOG programming skill demonstrated by the students.

EXISTENCE OF CENTRAL MENTAL GESTALTS

It is interesting to note that in the twelve programs completed by the students, some clearly express strong adherence to some central cognitive 'gestalts'about motion similar to the ones depicted earlier. On the other hand, some of the students' programs only consist of ad hoc rules, revealing no causal relationships between the goal statements and the conditions, and the ideas revealed in one rule seldom recur again in other rules. The following extract (fig. 2) taken from one of the students' programs gives a clear illustration of the ad hoc nature of the rules she has written.

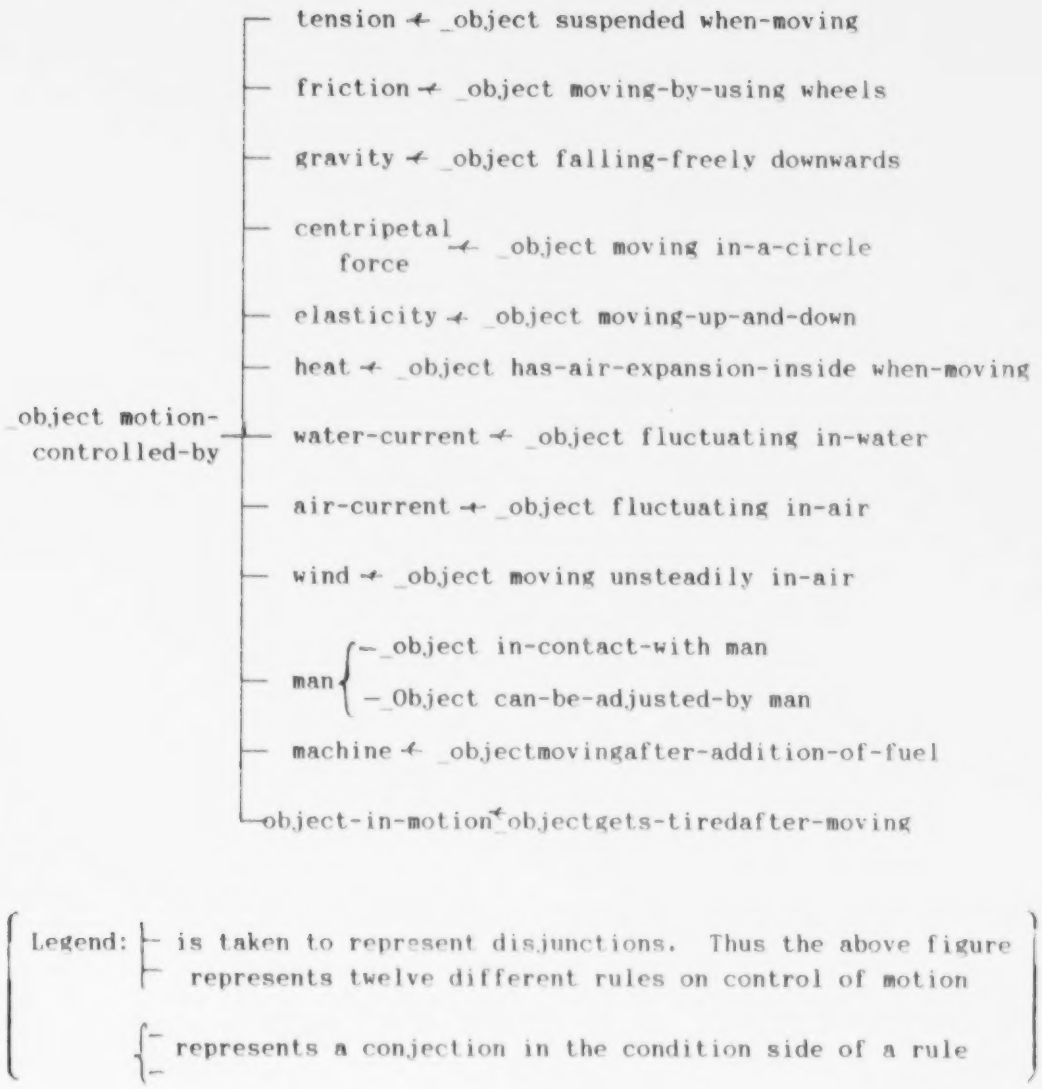
_object motion-controlled-by
tension ← _object suspended when-moving
friction ← _object moving-by-using wheels
gravity ← _object falling-freely downwards
centripetal force ← _object moving in-a-circle
elasticity ← _object moving-up-and-down
heat ← _object has-air-expansion-inside when-moving
water-current ← _object fluctuating in-water
air-current ← _object fluctuating in-air
wind ← _object moving unsteadily in-air
man
_object in-contact-with man
_Object can-be-adjusted-by man
machine ← _objectmovingafter-addition-of-fuel
object-in-motion ← objectgets-tiredafter-moving
Legend:
is taken to represent disjunctions. Thus the above figure represents twelve different rules on control of motion
represents a conjection in the condition side of a rule

Fig.2 A Portion of the Program written by Brenda represented in the form of a Network

Fig. 3 is a network representation of the work of another student in the same group - the 17-yr-old group. While Brenda's rules are all ah hoc in nature, Evon's program demonstrates clearly that she is using a central mental 'gestalt' similar to the one described earlier as the basis for constructing all her rules. In other words, Evon is desplaying a strong p;ersistent adherence to a framework of intuitive physics, while Brenda does not. This difference in the structure of students' programs appeared in the work of both age groups, suggesting that this feature may not be particularly age dependent.

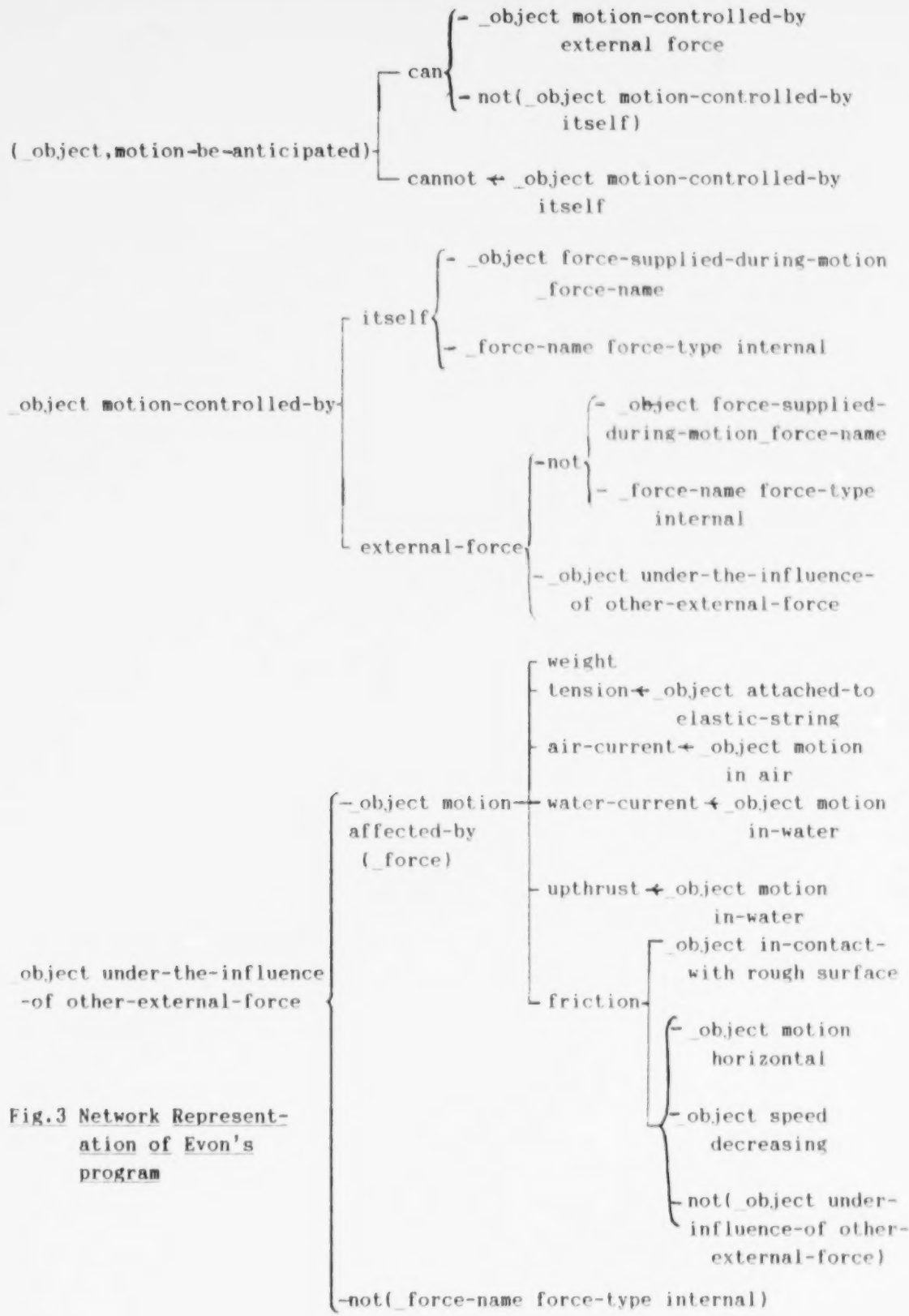

Fig.3 Network Representation of Evon's program

Ontological status of entities participating in the same relation

Another important dimension for analysing the degree of structuredness, or perhaps coherence, of the programs is the variety in the ontological status of entities participating in the same relation in the programs. Evon's program is quite well structured from this perspective - with the exception of the relation 'motion-controlled-by' where the entities for control of motion were 'itself' (which is an agent) and 'external-force', all the other relations were used for relating the same kind of entities. For example, in her program, the entities responsible for causing motion are all physical agents, and the entities that can affect motion are all different kinds of forces. On the other hand, Brenda's program is extremely unstructured (non-coherent) from this perspective - motion can be controlled by forces (like tension, friction, gravity), or material properties (like elasticity), or energy (like heat), or natural forces (like water current, wind) or physical agents (like man, machine or the object itself). This unstructuredness in the programs reflects a lack of clarity and rigour in the student's analysis of the situation. Difference along this dimension of structuredness appear in the work of both age groups - there are some very well structured programs in the work of the younger group as well as some very poorly structured programs in the work of the older group.

This kind of difference also gives us important insight as to the mode of integration of the student's learnt physics concepts with his/her intuitive understanding of motion. Both programs made reference to tension, a term which they only picked up in the context of their school physics. Evon explicitly placed tension as a force that may affect an object's motion. Furthermore, this force would be labelled as an external forceunder her scheme of intuitive understanding. For Brenda, her program did not put any explicit label to classify the ontology of the term 'tension', and as a matter of fact it was just grouped together with a variety of different kinds of entities. It seems that she has only some vague impression that tension somehow affects the motion of an object, and that this happens in cases when an object is suspended. The learning of physics has not helped her to build up a theoretical framework for analysing motion, and her only gain seems to be the acquisition of a new term which is associated with a very specific situation.

In the work of the younger age group, many fewer jargons and technical terms like tension and upthrust were used. Learned school physics has not had an opportunity to add such items to their vocabulary.

Consistency in the nature of conditions used for the same group of goal statements

For Evon's program, basically the same kind of conditions would be used for deciding among the same group of goal statements. For example, what controls motion would be decided by finding out what the nature of the source of supply of force is,- if the source of supply is internal, then the control would be itself, and the control would be by external force when otherwise. To decide what forces affect an object's motion, the criteria she uses would be to find out the actual physical situation of the object - what medium it moves in and what it is in contact with. For Brenda, the conditions for deciding what controls a particular motion vary a great deal from case to case and there is no general principle to guide the decision. The conditions may be the physical situation of the moving object, or the trajectory of the object, or even an animistic criterion of whether the moving object would get tired after moving. This lack of consistency in the nature of the conditions used again pertains very much to whether the student has a clear theoretical framework for looking at motion, even if it were an intuitive one.

Inter-relatedness of the rules

For the programs which display a definite adherence to a theoretical model for the interpretation of motion, the rules tend to fall into groups with inter-relationships linking the groups together. A careful look at fig. 3 show that the inter-relationships running between the groups of rules follow very closely that of the links between key concepts depicted in fig. 1. On the other hand, for a program that does not demonstrate any adherence to a clear theoretical model, the rules still fall into groups, but there are no links between the rule groups. It is just a flat structure displaying no hierarchical relationship between the concepts involved and the rules are all just one level associations.

KNOWLEDGE STRUCTURES AND EFFECTS OF INTERACTING WITH OWN KNOWLEDGE

The PROLOG programming environment together with the expert system shell provided readily allows the students to query the knowledge bases they developed, and also provides facilities to explain how the inferences were arrived at when required. This allows students to explore the logical consequences of their externalized ideas. During the process of development and modification of their programs, the students were unavoidably confronted with unexpected results. The nature of the cognitive conflict and what the student may gain from the interactions depends very much on whether the programs reflect any core theoretical hypothesis and its degree of structuredness.

In the case when the programs demonstrate a strong theoretical hypothesis,

the program normally fails because the fundamental assumptions/concepts are invalid. The normal strategy employed in such cases seems to be that of patching: he/she would try to adhere to the same basic theoretical framework and try to add in minor adjustments to get around the specific instances of failure, rather than to review the theoretical framework itself. The following episode taken from Evon's programming sessions is a typical example of one such interactions:

She had written the following rules for determining the cause of motion:

```
_object motion-caused-by itself if
     _object force-supplied-by _object

_object motion-caused-by machine if
     _object force-supplied-by machine

_object1 motion-caused-by _object2 if
     _object1 force-supplied-by _object2

_object motion-caused-by gravity if
     not(object under-the-influence-of other external-force)
```

She then set out to test the program with the case of a falling apple (thinking about the famous 'Newton's apple'). To her dismay, the computer did not come up with the expected answer. The reason was that in one of her earlier sessions, she included weight as an external (supply of) force, together with forces like friction, air current, etc. Faced with such a contradiction, her immediate response was to exclude weight from her list of external forces. As a matter of fact, in her scheme of intuitive physics, there was no clear orientation for classifying weight as internal or external forces since she could find justification for classifying it as either type of force. Weight arises because of attraction from the earth which is external to the object, so it makes sense to classify weight as external force. On the other hand, weight is related to the mass of the object which is an intrinsic property of the object itself, so it also makes sense to classify it as internal force. After changing weight to an internal force, the computer still did not give her the expected answer - gravity, because according to done of her other rules, anything placed in air would be affected by air-current, and air-current is an external force. Now, excluding air-current from the list of external forces seemed to be too much a twisting of facts, she just replaced the forth rule listed above by:

```
_object motion-caused-by gravity if
     not(_object motion-caused-by _something)
```

to avoid the problem with specific instances of internal or external forces. She did not review her underlying concepts about sources of supply of force, but then this was not the end of the problem for her.

She again met similar problems relating to internal and external supplies of force when she explored her rules on control of motion, and she could not find a satisfactory solution after patching in various parts of the program. At the end of the programming task, she was beginning to raise questions about the more central assumptions.

When the programs fail to give an expected answer, the kind of conflict faced by a student who do not hold a strong theoretical framework of intuitive physics, i.e. one whose program has an unstructured knowledge base, is much less serious and it was much easier to remedy by local patching. For them, the characteristics chosen to be put into the premises do not belong to the same ontological category. For example, whether something gets tired after moving describes the subjective feeling of an animate object whereas whether something needs fuel for motion is an objective fact. Yet both are used as defining characteristics for making inferences about the control of motion. When the program fails, the student's reaction was either that he/she has chosen a less appropriate characteristic, or that he/she has missed out some other important characteristics.

Looking at the interactions between the students and their own PROLOG programs, there is evidence that such explorations with one's own externalized knowledge do provide an opportunity for inconsistencies in one's ideas and concepts to show up. Further, when the knowledge base expressed is well structured, such interactions may eventually lead to fundamental restructuring of core concepts and hypothsis.

CONCLUSIONS

Results from the preliminary analysis indicate that it is possible to find out about a student's framework for conceptualization of motion through PROLOG programming. The elicited knowledge indicate that the intuitive ideas are not compartmentalized with respect to their learnt physics concepts, but rather become woven into their own intuitive of looking at the world of motion. The nature of the integration depends very much on how well structured their own knowledge base about motion are. Intuitive ideas may or may not be well structured, and the degree of structuring seems to pertain to the cognitive style of the individual, and does not bear any relation to the age of the student nor is it related to the amount of Physics the student has learnt. For the 17-yr-old group, it is the higher ability students who show a much better structuring of ideas than the lower ability group; but no such trend can be found in the younger group. Most of the students found the performance of the program containing the ad hoc rules more acceptable than the better structured ones.

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